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THE VALUE OF WIND-MILLS IN INDIA

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THE VALUE OF WIND-MILLS IN INDIA.

Previous to the advent of the steam-engine the wind-mill was held in high repute as a means of obtaining motive power, and it was largely used for grinding corn and for raising water for the drainage of low lands. The old-fashioned mill was cumbrous and expensive, and, as a rule, it was so heavily loaded that it only worked in strong winds. The disadvantages attendant on its use were many and serious and it is not surprising that it fell into disrepute. Subsequently the invention of the dynamo and the electrical accumulator again drew the attention of Engineers to the wind as a source of energy and the modern aermotor or wind-engine was gradually developed. The expectations based upon the conversion of the power of wind into electrical energy and its storage in accumulators have not been realized mainly because of the large capital outlay involved in the plant. But a very large field for the use of wind-engines has been found in employing them to pump water either for domestic purposes, for drainage or for irrigation, and at the present day many thousands are doing useful work in these directions. In no part of the world is there more scope for them than in India where millions of cattle are daily employed in raising water from wells for the irrigation of land but unfortunately they are too expensive for the individual ryot and there is a generally prevalent idea that the wind-currents in India are too light to make the amount of energy derivable from them of any material value.

About two years ago I was asked by the Board of Revenue to furnish them with information regarding the utility of wind-mills for irrigation work, and, as there was no trustworthy information available, I proposed to Messrs. Parry & Co., the Madras Agents of the Chicago Aermotor Company, that, if they would place an aermotor at my disposal for purely experimental work, I would undertake to collet and place on record the observations. After consultation with their principals in America, it was settled that a 16 ft. aermotor mounted on a 70 ft. tower should be handed over to me to experiment with and the Board of Revenue agreed to furnish the necessary funds.

A new aermotor was accordingly sent out, and I had it put up in the compound of the School of Arts, Madras. An attempt was made to sink a well, but the sub-soil proved so unsatisfactory that the well was abandoned and a masonry tank 10 ft. square and 5 ft. deep was constructed under the aermotor tower. It was originally intended that the aermotor should drive a rocking lever at the ground level, to which lever two pumps rods were to be attached, one working an 8″ pump, the other a 6″ pump, both to be fixed 25 ft. below ground level in the well. But when the well had to be given up it was found impracticable to arrange for driving two pumps except at a greater expense than was warranted and only the 8″ pump was fixed in the tank.

The object of the experiment was to ascertain the quantity of water which the wind-mill would lift to a certain height every day in the year, and as there was no necessity to use the water for any purpose it was decided that the pump should be arranged to lift the water 25 ft.

and allow it to fall back into the tank. To obtain the information required, a tacheometer was fitted to the pump to record every stroke, and to obtain the quantities of water lifted, it was only necessary to ascertain, as accurately as possible, the delivery of water per stroke. To do this, another tank 10 ft. square and 5 ft. deep was built above the level of the ground and the water discharged from the delivery pipe was carried to it by a two inch main fitted to the bottom of a wooden funnel into which the water lifted by the pump was discharged.

The aermotor and tower were bolted together horizontally on the ground and were then lifted into a vertical position by means of a derrick. The plan followed was the very ingenious one devised by the Aermotor Company, but it gave us a great deal of trouble, as the tower, though it has proved to be amply strong enough in the erect position, was not well adapted to resist the strains brought upon it during the process of lifting, notwithstanding the fact that the instructions of the Aermotor Company were carefully carried out in regard to the addition of temporary bracing to resist the bending stresses. The wind-wheel was geared down to work the pump in the ratio of 3⅓ to 1. The diameter of the pump was 8 inches and the length of the stroke 16 inches, so that the theoretic discharge of the pump was 2·9 gallons per stroke. Careful experiments repeated a great number of times by recording the number of strokes required to fill the measuring tank showed that the average quantity of water delivered by each stroke of the pump was 2·5 gallons or 86 per cent. of the theoretic delivery. After preliminary experiments a daily record of the work done by the wind-mill was kept from the end of March 1902, and readings of the tacheometer were taken every morning at 8 A.M., at mid-day and at 4 P.M. It was at first intended to set up an anemometer to record wind velocities, but after careful consideration of the matter it was finally decided to dispense with the anemometer readings and to obtain all the information regarding the wind movements from the Observatory in Madras which is situated not much more than a mile away. The aermotor was 70 ft. above the ground and well above the influence of obstructions to the wind caused by buildings and trees, and as the whole country, for miles round, is a practically dead level plain, it was thought that, considering the observations were to be extended over a long period of time, it would be better to accept the Observatory anemometric determinations than to admit a new set with instruments not so carefully calibrated as those of the Government Observatory.

The aermotor has now been in operation for more than one year and sufficient information has been obtained to decide the question as to the suitability of these machines for irrigation work in India. Mr. R. Ll. Jones, the Deputy Director in charge of the Madras Observatory, has been kind enough to furnish me with a copy of the Observatory wind records for the whole year, and this statement gives not only the daily wind velocity in miles but also the movement of the wind in miles for every hour throughout the year. He has also been kind enough to furnish me with other data regarding wind movements in India of which, as will be subsequently seen, considerable use has been made in this paper and I am greatly indebted to him for his courtesy in this matter. Mr. J. Cook of the Central College, Bangalore, and Director of Meteorology in Mysore, has also been kind enough to send me valuable extracts from the records of his Observatories and I am glad to acknowledge my indebtedness to him for the same.

It seems unnecessary to publish the whole of the data which have been collected, but as a sample of the records for the whole year Table I summarizes the results of the observations made during the month of June.

TABLE I.

Observations made during the month of June.

Date.	Hour.	Number of strokes of pump during interval.	Number of strokes of pump per day.	Wind movement in miles during interval.	Wind movement in miles per day.
1	Noon.				
	4 P.M.	2,022		39	
2	8 A.M.	5,246		105	
	Noon.	2,028		40	
	4 P.M.	3,783	16,220	50	269
3	8 A.M.	10,409		179	
	Noon.	3,059		47	
	4 P.M.	3,718	17,412	60	283
4	8 A.M.	10,635		176	
6	4 P.M.				
7	8 A.M.	7,912		142	
	Noon.	2,880		49	
	4 P.M.	1,029		42	
9	8 A.M.				
	Noon.	2,656		54	
	4 P.M.	3,453	16,003	54	277
10	8 A.M.	9,894		169	
	Noon.	1,626		55	
	4 P.M.	3,501	14,492	56	261
11	8 A.M.	9,365		150	
12	Noon.				
	4 P.M.	•2,730		35	
13	8 A.M.	6,982		132	
	Noon.	2,498		53	
	4 P.M.	2,883	8,309	48	182
14	8 A.M.	3,228		81	
	Noon.	3,023		58	
	4 P.M.	3,403	9,561	48	185
15	8 A.M.	3,135		79	
	Noon.	3,350		6	
	4 P.M.	2,732	8,141	44	171
16	8 A.M.	2,059		65	
	Noon.	1,886		39	
	4 P.M.	2,384	8,509	46	187
17	8 A.M.	4,239		102	
	Noon.	1,054		36	
	4 P.M.	1,460	7,247	29	169
18	8 A.M.	4,733		104	
	Noon.	1,227		29	
	4 P.M.	1,781	8,720	35	181
19	8 A.M.	5,712		117	
	Noon.	1,220		30	
	4 P.M.	1,188	8,755	34	196
20	8 A.M.	6,347		132	
	Noon.	1,827		34	
	4 P.M.	929	4,621	19	134
21	8 A.M.	1,872		81	
	Noon.	1,838		36	
	4 P.M.	830	7,478	32	197
22	8 A.M.	4,810		129	
	Noon.	2,562		54	
	4 P.M.	1,598	8,176	31	189
23	8 A.M.	4,016		104	
	Noon.				
	4 P.M.	668		23	
24	8 A.M.	4,773		115	
	Noon.	1,793		35	
	4 P.M.	2,262	12,720	41	226
25	8 A.M.	8,665		150	
	Noon.	2,154		42	
	4 P.M.	2,707	12,971	47	230
26	8 A.M.	8,110		141	
	Noon.	1,590		37	
	4 P.M.	2,514	11,582	43	221
27	8 A.M.	7,478		141	
	Noon.	1,737		40	
	4 P.M.				
28	8 A.M.	7,003		127	
	Noon.	1,350		41	
	4 P.M.	1,631	6,968	38	179
29	8 A.M.	3,987		100	
	Noon.	2,702		56	
	4 P.M.	4,325	13,621	58	243
30	8 A.M.	6,594		129	
	Noon.	1,103		31	
	4 P.M.	2,906	8,802	44	182
1st July	8 A.M.	4,793		107	

To determine the ratio between the work done by the wind-mill and the daily velocity of the wind in miles was the main object of the experiments and this was easily done by plotting the observations on section paper, plate I, taking as ordinates the number of gallons of water lifted 25 ft. per day and as abscissae the wind movement in miles per day. When the observations had all been plotted, it was found that a straight line having the equation

$$X = 175\ (Y - 53)$$

represented the results very satisfactorily, where X is equal to the number of gallons of water lifted 25 ft. per day and Y is the daily movement of the wind in miles.

General observations of the working of the wind-mill show that the strongest and steadiest winds generally blow in Madras from noon till about 5 o'clock in the afternoon, and from an examination of the Observatory records, it was found that, on a considerable number of afternoons during the year, the wind blew with an almost constant hourly velocity, and from a selection of such days, a second curve (plate II) was plotted having as ordinates the work done by the wind-mill from 12 to 4 P.M. and as abscissae the total wind movement during that period. The equation

$$Y = 156{\cdot}87\ X$$

represents these results with very great accuracy whenever the wind velocity averages more than 8 miles per hour during the period. Careful observations on several days with an anemometer fixed to the wind-mill tower showed that it required a steady breeze of about 7½ miles per hour to keep the wind-mill in continuous motion, but that, when the wind velocity exceeded 3 miles per hour, a certain amount of work was done as the result of puffs of wind. These facts are very clearly shown by the curve on plate II. From the first equation it will be seen that, when the daily wind velocity is below 53 miles per day, the amount of work done by the wind-mill is negligible, but that above that velocity it steadily increases in direct proportion to the increased rate of the movement of the wind. This same result is also obtained from the second equation, and it is one of extreme importance because makers of wind-mills invariably claim that the work done by a wind-mill is proportional to the cube of the wind velocity; and in their catalogues and price lists they publish fictitious tables showing the work done by the wind at various velocities.

Table II has been compiled from the average wind velocities measured at the Observatory in Madras during the 30 years 1864-1894, using equation (1) to determine the average amount of water which the wind-mill can lift.

The other columns in this table show (1) the depth to which an acre of land would be covered during the month by the water lifted by the wind-mill; (2) the average monthly rainfall; and (3) the depth of water which would be supplied to 10 acres of land by adding to the natural rainfall the quantity of water lifted by the pump. The months of February and October are the least windy in the year but during the former the harvest is in general progress whilst during the latter the rainfall is usually heavy. In March and April there is practically no rain, but the water delivered by the wind-mill would be more than sufficient for the seed-beds required for an area of over 10 acres. During May, June and July strong winds are prevalent and the water lifted by the wind-mill added to the average rainfall would cover a field of 10 acres to a depth of over 6 inches. This is sufficient with careful use for the irrigation of almost any crop, and I am therefore of opinion that a 16 ft. aermotor will do sufficient work in Madras to irrigate 10 acres of land when the water has to be lifted 25 ft.

TABLE II.

Month.	Wind; daily velocity in miles.	Rainfall in inches during the *month.*	Gallons of water lifted per day 25 feet.	Inches depth on 10 acres per month.	Total rainfall and water lifted, inches on 10 acres.
January ...	144	0·89	15,920	2·18	3·07
February ...	122	0·28	12,070	1·49	1·77
March	152	0·39	17,318	2·37	2·76
April	191	0·62	24,140	3·20	3·82
May	227	2·12	30,450	4·09	6·21
June	220	2·11	29,215	3·87	5·98
July	198	3·87	25,380	3·47	7·34
August	174	4·56	21,180	2·89	7·45
September ...	156	4·69	18,020	2·39	7·08
October ...	123	11·00	12,240	1·62	12·62
November ...	165	13·21	19,600	2·60	15·81
December ...	183	5·28	22,740	3·11	8·39

Before discussing these results further, it will be well to give a brief *resumé* of the results of experiments on wind-mills which have been made in other parts of the world. In "The Water-supply and Irrigation Papers" published by the United States Geological Survey No. 20 gives an account of an extensive series of experiments with wind-mills made by Mr. Thomas Perry. The experiments were carried out with extreme accuracy and with very elaborate apparatus and the results of them may be summarized as follows:—

(1) The maximum work which can be done by a wind-mill is proportional to the cube of the wind velocity.

(2) The starting power of a wind-mill is proportional to the square of the wind velocity.

(3) The speed of an unloaded wheel increases in a somewhat greater ratio than the velocity of the wind, but for practical purposes there will be but little error in assuming that the unloaded wheel revolves at a speed proportional to the wind velocity.

(4) The best speed for a wind-mill is from 0·55 to 0·70 the speed at which it runs when unloaded.

(5) The best load for a wind-mill at any given velocity of the wind is from one-half to two-thirds the maximum starting force at that velocity of the wind.

A large number of experiments were made to determine the best form for the vanes of a wind-mill and the best result obtained showed that a 12 ft. wheel having an area of 113 sq.ft. developed 6,836 foot-pounds of work in a ten-mile wind, or, in other words, that a 12 ft. wind-mill could be made to develop 0·207 H.P. in a ten-mile wind. This result is corroborated by experiments conducted in Denmark at the Government Experimental wind-mill erected at Askov. There it was found that the best result that could be obtained, when applied to a 12 ft. wind-mill would give 0·234 H.P. in a ten-mile wind. These results can be very approximately expressed in the following way: *The maximum work which can be done by a wind-mill in a ten-mile breeze is equal to one foot-pound per second per square foot of wind surface.* A 16 ft. wind-wheel has an area of 201 sq.ft., and should therefore supply in a ten-mile wind 201 foot-pounds of work per second equivalent to 0·373 H.P. From the equation $Y = 156·87 X$, it is found that the actual work represented by the water lifted is 0·198 H.P. or 53 per cent. of the maximum work that can be obtained from the wind. Allowing for the friction of the gearing and the loss of energy in the pump, the efficiency is satisfactory and the load on the pump is evidently suitable.

A careful consideration of these results leads to several very important conclusions which are entirely confirmed by the experiments on the aermotor. Although the maximum work which can be done by a wind-mill is proportional to the cube of the wind velocity the actual amount of work which it does when pumping water is proportional to the wind velocity, because the work done depends upon the number of strokes of the pump, and the number of strokes of the pump depends upon the velocity of rotation of the wind-mill, and this, we have seen, is approximately proportional to the wind velocity. This result is fully borne out by these experiments since the work done by the aermotor is found to be exactly proportional to the wind velocity. A similar result was obtained by Mr. W. H. Moreland, I.C.S., the Director of the Department of Land Records and Agriculture in the United Provinces, who, in "A Note on Trials of an Aermotor in Well Irrigation" published as bulletin No. 11 of the Agricultural Series of his Department, gives a table on page 3 which shows that the quantity of water raised at different velocities of wind was approximately proportional to the wind velocity. The practical meaning of this is that a wind-mill works with the greatest efficiency when the velocity of the wind is just sufficient to keep it in steady motion and that at any other higher velocity of the wind but a portion of the useful work which the wind-mill could do is utilized. If a convenient arrangement could be devised whereby the load put upon the wind-mill varied with the square of the wind velocity the work done by these machines would be much greater. An attempt to realize this is made by the Chicago Aermotor Company who provide means whereby three different lengths of stroke of pump can be obtained, but in practice, it is found inconvenient to alter the length of the stroke. The most satisfactory way to vary the load on a wind-mill is to provide it with two pumps worked through a rocking lever fixed at ground level. One pump can be permanently attached to the rocking lever and the other whenever the wind velocity is sufficient to justify doing so.

Table II has been compiled from the results obtained with a single pump of 8 inches diameter and 16 inches stroke, but it is certain that for the greater part of the year for several hours each day the aermotor would have been capable of working two such pumps with practically no loss of speed.

TABLE III.

Mean hourly air movement at Madras (irrespective of direction).

——	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Mid-1 ...	3·70	2·68	3·34	4·94	8·45	8·37	7·64	7·19	5·88	3·18	4·78	4·62
1-2 ...	3·37	2·48	2·93	4·10	7·90	8·42	7·56	7·25	6·00	3·20	4·59	4·49
2-3 ...	3·22	2·30	2·58	3·62	7·45	8·09	7·23	6·61	6·01	3·40	4·47	4·28
3-4 ...	3·15	2·28	2·52	3·41	7·21	8·01	6·86	6·51	6·02	3·55	4·73	4·04
4-5 ...	3·03	2·15	2·67	3·29	6·97	7·64	6·70	6·08	5·83	3·33	4·70	3·99
5-6 ...	3·00	2·20	2·53	3·16	6·84	7·17	6·33	5·77	5·53	3·24	4·52	4·08
6-7 ...	3·09	2·21	2·55	3·87	7·52	7·54	6·26	5·68	5·68	3·45	4·64	4·15
7-8 ...	3·43	2·82	4·16	6·92	9·82	9·34	8·02	6·85	7·08	4·60	5·59	5·15
8-9 ...	5·51	4·67	6·41	8·92	10·62	11·14	9·83	8·44	8·64	5·68	7·13	7·37
9-10 ...	7·66	6·38	7·78	9·86	10·78	12·28	11·21	9·51	9·54	6·43	8·72	9·72
10-11 ...	*9·27*	*7·45*	*8·77*	*10·91*	*10·80*	*12·63*	*11·90*	*10·10*	*9·54*	7·18	9·96	11·11
11-Noon.	10·11	8·43	10·14	12·53	11·70	12·72	11·97	10·12	9·56	7·59	10·77	12·01
Noon-13 ...	10·43	9·29	10·86	13·41	12·36	12·33	11·45	9·90	9·34	8·11	11·20	12·35
13-14 ...	11·13	10·06	11·68	14·16	13·31	12·51	11·42	9·97	9·21	8·64	11·38	12·69
14-15 ...	11·14	10·22	11·91	14·05	13·41	12·46	10·90	9·63	9·10	8·75	11·33	12·45
15-16 ...	11·04	10·14	11·91	13·89	13·31	12·09	10·59	9·15	8·53	8·49	11·28	12·25
16-17 ...	10·37	9·81	11·24	13·07	12·48	11·18	9·64	8·02	7·66	7·76	10·14	11·24
17-18 ...	8·75	8·50	9·70	11·41	11·59	10·18	8·77	7·35	6·26	5·84	8·21	9·03
18-19 ...	6·57	6·37	7·43	9·41	10·40	9·42	7·94	6·27	5·06	4·58	7·05	7·28
19-20 ...	5·86	5·43	6·53	8·40	10·03	9·00	7·86	5·95	5·13	4·07	6·58	6·74
20-21 ...	5·34	4·87	5·89	7·83	9·81	8·90	7·89	6·10	4·98	3·66	5·98	6·34
21-22 ...	4·01	4·48	5·41	7·22	9·70	8·80	8·09	6·71	4·91	3·44	5·68	5·92
22-23 ..	4·43	3·68	4·78	6·48	9·33	8·67	7·69	7·01	5·30	3·22	5·33	5·50
23-Mid.	4·07	3·30	4·09	5·86	8·86	8·43	7·57	7·26	5·65	3·24	4·95	5·11

Table III gives the mean hourly movement of wind at Madras irrespective of direction and by using this table we can approximately estimate what extra work would have been done if it had been possible to attach a second 8-inch pump to the wind-mill whenever the velocity of the wind was sufficient to drive two pumps. With a wind velocity of 8 miles per hour and one 8-inch pump the wind-mill works steadily; with double the load, since the power of the wind-mill is porportional to the cube of the velocity of the wind, a wind velocity of 10·08 miles per hour would be required.

From Table III, Table IV has been compiled by taking out for each month the average number of hours in the month during which the wind velocity was over 8 miles per hour, and also the number of hours

2

in each month during which the wind velocity averaged over 10·08 miles per hour. From the totals it will be seen that the wind was strong enough during 3,791 hours to drive one pump and sufficiently strong during 1,985 hours to drive two pumps. This means, that, neglecting any work done by the wind when the average velocity was below 8 miles per hour, the total quantity of water raised by the wind-mill during the year would have been increased by 52·4 per cent. if another pump could have been attached when the wind was favourable. To drive three pumps the wind velocity would have to be 11·54 miles per hour and the table shows that this velocity was exceeded during 917 hours in the year, so that the addition of a third pump would have increased the work done by a further 24·3 per cent. If a 10-inch pump had been attached to the wind-mill instead of an 8-inch pump, a wind velocity of 9·28 miles per hour would have been required.

Table IV shows that during the year the wind exceeded this velocity during 2,795 hours and the quantity of water which would have been lifted by the 10-inch pump would have been almost exactly equal to that which was lifted by the 8-inch pump, as when the 10-inch pump is working, it will in any given time lift 1·345 times as much water as the 8-inch pump. An examination of the figures given in Table IV shows that with the 8-inch pump the volume of water lifted is more *uniformly distributed throughout the year* than would be the case if the larger pump were used, and we may fairly assume that an 8-inch pump is more suitable for work with a 16-feet aermotor in Madras than a 10-inch pump would be. It is important to notice, however, that the difference is not very material and that, in places where the wind distribution is anything like that at Madras, the size of the pump may vary within considerable limits without materially affecting the quantity of water which would be lifted.

TABLE IV.

Number of hours in each month the wind movement per hour exceeded 8 miles (A), exceeded 10·08 *miles (B), exceeded* 11·54 *miles (C), exceeded* 9·28 *miles (D).*

Month.	A	B	C	D
January	248	186	...	217
February	196	56	...	140
March	248	186	93	217
April	360	240	180	360
May	558	341	217	496
June	630	300	210	360
July	372	217	62	279
August	279	62	...	186
September	240	...	...	120
October	120	...	...	...
November	270	180	...	283
December	270	217	155	363
Total ...	3,791	1,985	917	2,795

TABLE V.

*Mean hourly wind velocity—Bangalore.**

—	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Mid–1	9·5	9·5	8·2	7·4	10·2	12·2	12·3	10·5	8·3	6·8	7·2	8·7
1–2	9·0	8·4	7·3	6·9	10·1	11·9	12·2	10·5	7·5	6·3	6·9	8·5
2–3	8·7	7·9	6·5	6·7	9·9	11·6	11·9	10·3	7·5	6·1	6·8	8·3
3–4	8·5	7·6	6·1	6·2	9·1	11·5	12·0	10·1	7·3	5·8	6·4	8·2
4–5	8·1	7·2	5·7	5·9	8·7	11·1	11·8	9·8	8·0	5·6	6·3	8·0
5–6	7·9	6·7	5·2	5·4	8·6	10·9	11·6	9·8	6·7	5·2	6·2	8·4
6–7	7·8	6·4	5·1	5·8	8·7	11·4	12·1	10·0	6·9	5·6	6·1	8·4
7–8	8·4	7·2	6·2	7·0	9·8	12·9	13·5	11·4	8·2	7·1	7·8	10·3
8–9	10·5	9·0	7·8	7·3	9·9	14·4	15·1	12·6	8·9	8·2	9·4	12·5
9–10	11·0	10·5	8·8	7·4	10·1	15·2	16·1	13·7	9·4	8·5	10·2	12·9
10–11	11·7	11·3	9·8	7·5	9·9	16·0	17·3	14·3	9·8	8·9	10·6	13·0
11–Noon	11·6	11·4	10·1	8·0	9·8	16·3	17·8	14·5	10·0	9·2	10·2	12·9
Noon–13	11·3	11·3	11·0	9·1	9·5	16·3	17·8	14·5	9·8	9·1	9·8	12·4
13–14	11·3	11·6	11·6	9·7	9·3	16·3	18·1	14·4	9·6	9·1	9·8	12·1
14–15	11·1	11·8	11·9	10·6	9·3	15·8	17·5	14·0	9·5	8·9	9·5	12·1
15–16	10·9	10·9	11·4	10·7	9·5	15·4	17·5	13·7	8·8	8·8	9·2	11·4
16–17	10·4	10·6	10·9	10·6	9·3	15·1	16·9	12·6	8·3	8·0	8·6	10·8
17–18	8·8	9·4	9·8	9·8	9·1	14·7	15·5	11·6	7·1	6·8	7·0	8·8
18–19	7·5	8·0	8·1	8·0	7·6	13·4	14·1	10·1	6·2	6·1	6·5	8·1
19–20	8·3	9·0	8·8	7·6	7·1	12·4	13·4	9·9	6·3	6·0	7·1	8·4
20–21	9·0	9·9	10·0	8·4	7·7	12·5	13·2	10·2	6·8	6·4	7·6	8·5
21–22	9·3	10·6	10·1	8·4	8·5	12·6	12·9	10·4	7·3	6·5	7·3	8·8
22–23	9·4	10·7	9·9	8·0	9·4	12·5	12·7	10·4	7·8	6·5	7·5	9·0
23–Mid.	9·4	10·3	9·2	7·7	10·0	12·1	12·4	10·4	8·0	6·9	7·5	8·9
Total ...	229·0	227·2	209·1	189·8	220·8	326·9	345·9	279·5	193·1	172·2	191·3	239·0

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* The figures in this table are taken from the Memoirs of the Mysore Meteorological Department and are not comparable with the figures for Bangalore in Table VII.

TABLE VI.

Number of hours in each month the wind movement per hour exceeded 8·28 *miles* (*A*), *exceeded* 10·43 *miles* (*B*), *exceeded* 11·91 *miles* (*C*), *exceeded* 9·50 *miles* (*D*).

—	A	B	C	D
January	620	279	...	310
February	448	308	...	304
March	434	155	...	310
April	240	90	...	155
May	651	...	...	341
June	720	720	540	720
July	744	744	651	744
August	744	403	279	744
September	300	...	...	150
October	217	. .	..	..
November	270	30	..	180
December	651	279	217	310
Total ..	6,039	3,008	1,687	4,328

Table V extracted from the Mysore Meteorological papers gives the mean hourly wind velocity during the four years (1895 to 1898) at Bangalore, and from this table we have constructed Table VI, similar to Table IV, in order to frame an estimate of what would be the work done by a similar aermotor in that locality. As the station is over 3,000 feet above the level of the sea, the density of the air is less and may be assumed to be 0·9 of that at sea level. As the work done by the wind is proportional to the mass multiplied by the cube of the velocity, a wind of 8 miles per hour at sea level will be as effective as one of 8·28 miles per hour at 3,000 feet elevation. The totals of the columns of Table V show, that a single 8-inch pump could be worked for 6,039 hours and that two pumps could be worked for 3,008 hours, whilst three pumps could be worked for 1,687 hours, giving an increase to the amount of water lifted of 50 per cent. for two pumps and a further increase of 28 per cent. for a third pump. If a 10-inch pump were used, it would work for 4,328 hours; this number multiplied by 1·35, the ratio of the work done by the two pumps in any given wind shows that the 10-inch pump would only lift 96·7 per cent. of the water lifted by an 8-inch pump, and an examination of the table shows that the greater part of this work would be done during the three monsoon months and that during the rest of the year the 8-inch pump would be immensely more effective than a 10-inch pump. From these figures, it would appear that the wind movements in Bangalore are so much stronger than in Madras that the work which a 16-ft. aermotor would do would be 60 per cent. greater. It would be interesting to extend this method of investigating the prospects of a wind-mill to a number of other places in India, but the hourly data are not available, and we must content ourselves with the daily returns published by the Meteorological Department. In Table VII the average daily wind velocity for each month in the year for some 28 stations fairly evenly distributed over India is given.

TABLE VII.

—	Calcutta.	Cuttack.	Patna.	Allahabad.	Lucknow.	Meerut.	Lahore.	Peshawar.	Karachi.	Deesa.	Surat.	Belgaum.	Sholapur.	Poona.	Nagpur.	Jubbulpur.	Secunderabad.	Bombay.	Karwar.	Madura.	Salem.	Bangalore.	Mysore.	Trichinopoly.	*Madras.*	Masulipatam.	Bellary.	Gopalpur.
January ...	62	34	48	81	58	49	43	64	239	208	125	249	184	134	93	53	90	289	73	130	117	184	212	113	141	125	81	156
February ...	80	53	70	100	79	68	54	82	249	211	130	237	174	149	123	60	97	251	86	120	128	175	188	93	119	122	92	240
March ...	118	84	82	110	96	66	70	91	281	209	156	272	190	190	133	72	105	270	96	98	126	168	192	91	150	163	109	283
April	169	122	106	117	106	60	77	104	329	228	192	320	213	234	161	84	113	264	98	86	110	158	195	96	185	211	127	348
May	172	122	115	149	103	64	79	116	407	325	305	424	255	342	228	108	173	247	128	89	98	176	249	144	219	214	201	319
June	142	96	101	166	101	64	88	113	423	397	374	556	316	360	240	127	217	576	128	115	113	263	358	221	212	226	251	278
July	122	77	86	151	94	57	80	107	415	351	377	647	336	386	243	120	249	450	123	110	108	267	348	238	191	233	282	271
August ...	115	62	77	134	72	48	69	93	397	278	326	517	296	327	191	119	203	376	87	89	93	237	312	197	166	187	263	218
September ...	98	202	70	128	67	46	50	73	356	200	221	385	245	274	147	82	150	267	58	82	82	176	240	170	140	154	223	173
October ...	67	46	46	66	46	31	39	60	235	161	122	241	193	139	102	50	96	226	54	70	60	139	176	91	118	106	104	151
November ...	62	41	36	49	34	29	32	51	193	181	142	267	199	138	95	43	88	235	60	91	74	167	206	101	156	132	77	168
December ...	61	31	41	60	41	37	33	61	217	194	120	299	182	133	83	43	81	236	66	118	92	195	256	120	178	137	76	160
Average daily wind movement, M. ...	106	81	73	109	75	52	60	85	312	245	216	368	232	234	153	79	139	287	88	100	100	192	244	140	165	167	157	231
M—53.	53	28	20	56	21	0	7	32	259	192	160	313	179	181	100	26	86	234	35	47	47	139	191	87	112	114	104	178
$\frac{M-53}{165-53}$*	0·47	0·25	0·18	0·50	0·18	0	0·05	0·29	2·32	1·71	1·43	2·80	1·60	1·62	0·89	0·23	0·77	2·09	0·31	0·42	0·42	1·24	7·0	0·78	1	1·02	0·93	1·59
$\left(\frac{M}{165}\right)$	0·64	0·49	0·443	0·662	0·452	0·314	0·36	0·512	1·876	1·485	1·307	2·425	1·405	1·415	0·928	0·48	0·839	1·735	0·534	0·605	0·606	1·163	1·48	0·848	1	1·013	0·952	1·40
$\frac{M^2}{(165)^2}$	0·41	0·24	0·19	0·44	0·20	0·10	0.13	0·26	3·52	2·20	1·72	5·90	1·97	2·00	0·86	0·23	0·70	3·02	0·28	0·37	0·37	1·35	2·19	0·72	1	1·05	0·90	1·96

* 165 is the average daily wind movement in Madras where these experiments were made.

We have seen that the work done by the aermotor in Madras is proportional to the daily velocity of the wind, the equation being $X = 175\ (Y - 53)$. Applying this equation to the figures giving the average daily velocity throughout the year we obtain the ratio given in the horizontal line $\left(\frac{M-53}{165-53}\right)$. This method is based upon the assumption that an 8-inch pump is in use. *But in places of low wind velocity* it would be advisable to use a smaller pump, and in places of much higher wind velocity better results will be obtained with a larger pump. We *have seen that the energy of the wind is proportional to the cube of the* velocity and that the starting power of the wind is proportional to the square of the velocity, and it therefore seems not unreasonable to assume that the energy which can be derived from the wind may be taken as approximately equal to the square of the daily wind velocity. In Table VII is given the ratio of the average wind velocity at each place to the average wind velocity in Madras $\left(\frac{M}{165}\right)$ and the squares of these numbers $\left(\frac{M}{165}\right)^2$. A comparison of the two sets of figures, $\frac{M-53}{165-53}$ and $\left(\frac{M}{165}\right)^2$ shows that only in places of extremely low or extremely high wind velocity is there any very material difference, and for this reason, I am inclined to think that the latter method of estimating the probable amount of work which can be obtained from a wind-mill in any locality is the more accurate.

It will be seen that at the great majority of stations the wind forces are so slight that we may unhesitatingly say that wind-mills are of no value. There remain, however, a certain number of stations where the conditions are favourable, and as these represent the wind conditions prevailing over an enormous tract of country, we arrive at this result: that, though over the greater part of India including the whole of Northern India, the energy of the wind is of no practical value, yet there are many places in peninsular India where it should be profitable to make use of wind-mills for irrigation. Along the sea coast from Karachee to Bombay and from Diamond Harbour to Negapatam, over a large tract of the Deccan, over the Mysore Plateau and probably in most of the hill-stations, it will be found that wind-mills, if not absolutely ideal machines for lifting water, are by far the cheapest and most convenient of mechanical devices available. From the equation which has been obtained as the result of observations in Madras, it is easy to calculate the effective horse-power obtained from a wind-mill, and it will be seen that when the load is fixed, as it is by the size of the pump and the height over which the water is lifted, the actual horse-power of the wind-mill is not very large even when strong breezes are blowing. On the other hand, it must be remembered that a wind-wheel of from 12 to 20 ft. in diameter would be sufficiently large to extract all the water that can be obtained from the majority of wells sunk in this country, and that, as it is most effective in hot dry weather, *it is a more convenient aid to irrigation than at first sight* might be expected. We have seen that the amount of effective work which a wind-mill can do is increased 50 per cent. by the addition of a second pump, and as the cost of this addition is comparatively small compared with the cost of a wind-mill tower and one pump, I strongly recommend that all wind-mills erected for lifting water should be arranged so as to be able to drive two pumps during periods when the wind velocity is sufficiently high. Taken as a whole, the movements of the wind in India, though very much feebler than in temperate climates, are fairly reliable and conveniently distributed, the maximum wind force usually occurring in the afternoon when the water in the well will probably be at its lowest level and the work of lifting it out therefore greatest. It may also be noted that, as a rule, during rainy weather the wind movements are feeble, but water for irrigation is not wanted then; whilst hot dry weather, when water is most wanted, is usually accompanied by strong winds. The actual results of irrigation with aermotors should therefore be somewhat more favourable than calculations based on average returns indicate.

As the result of experience with the working of the aermotor supplied by the Chicago Company, I am of opinion that these machines are not sufficiently strongly constructed for work in India. A good many minor breakages have occurred during the course of the experiments, but the most serious defects were due to the bad fitting of the valves in the pump chamber. The design seems to be excellent, but the execution was bad and much trouble might have been obviated if the pivots on which the flap valves turn had been made larger and fitted into better designed sockets. A wind-engine and pump cannot be placed in inexperienced hands, they require carefully looking after, and the slightest defect or damage should be remedied immediately it occurs. It will not pay to keep an experienced fitter to look after a single wind-mill, but the man could easily look after a dozen mills and where such colonies of wind-mills can be established they will prove extremely remunerative investments.

A 16-feet aermotor mounted on a 40-ft. tower and fitted with an 8-inch pump will cost, when erected over a well, about Rs. 1,500, and we may assume that the cost of maintaining the same in good order will be about Rs. 5 a month. Such investments should yield about 6 per cent. interest on the capital expended, or Rs. 7-8-0 a month. Ten per cent. for depreciation is perhaps an excessive amount to allow, but it will be well on the safe side if we do so. This comes to Rs. 12-8-0 a month, making the total cost of the wind-mill Rs. 25 a month. Now, this wind-mill will do as much work as at least 2 pairs of good cattle, and if fitted with two pumps it will be equivalent to 3 pairs of cattle and the cost of lifting water with them will amount to from Rs. 45 to Rs. 67 a month, showing a margin in favour of the wind-mill of from Rs. 20 to Rs. 40 a month. This is the result that can be obtained in Madras, but there are thousands of square miles of country in India where much more favourable results can be obtained, and I therefore conclude this brief account of my observations on a wind-mill in Madras with the statement that there is a wide field in India open for the profitable employment of wind-mills in lifting water for irrigation.

ALFRED CHATTERTON.

MADRAS, PRINTED BY THE SUPERINTENDENT, GOVERNMENT PRESS.—1903.

PLATE I.

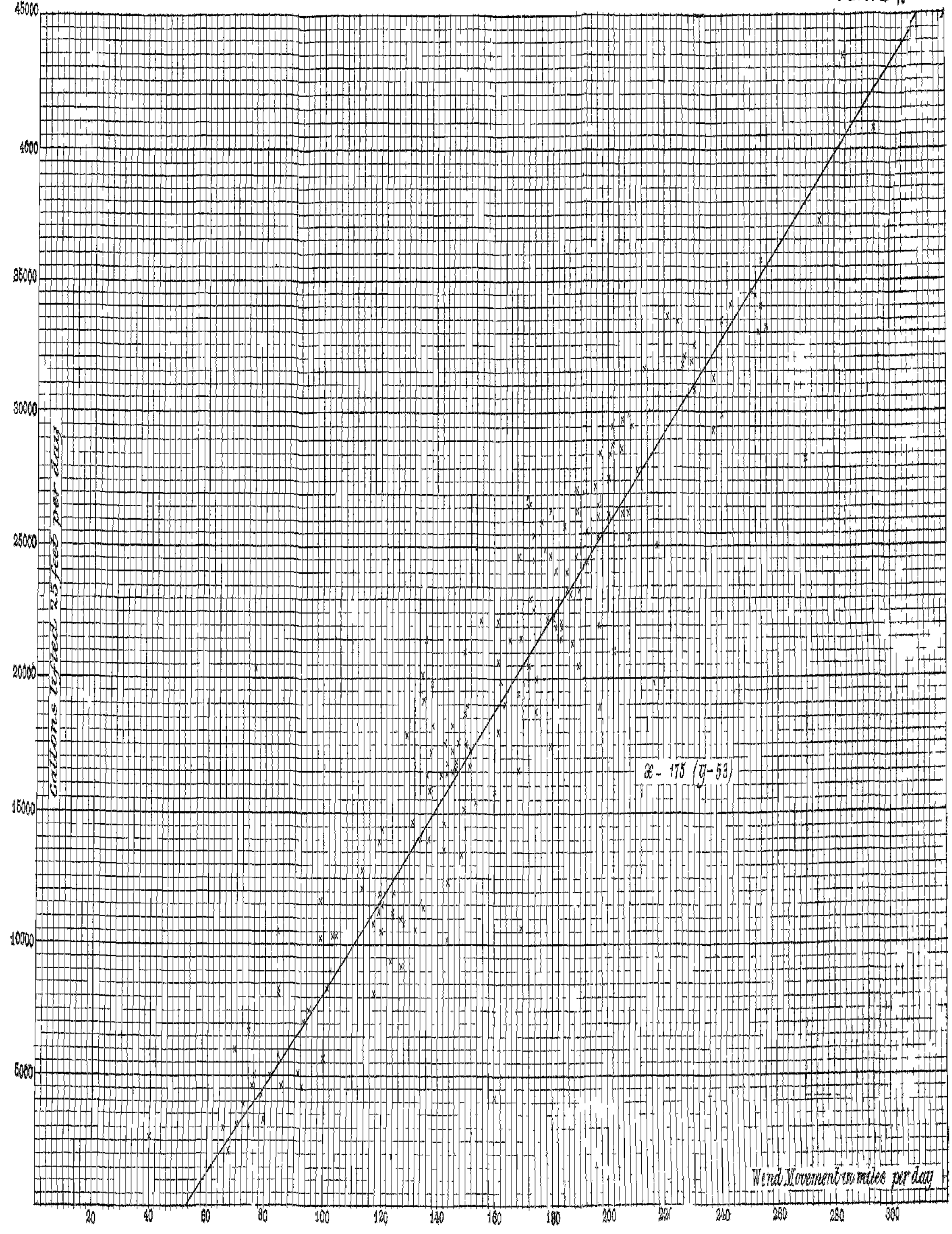
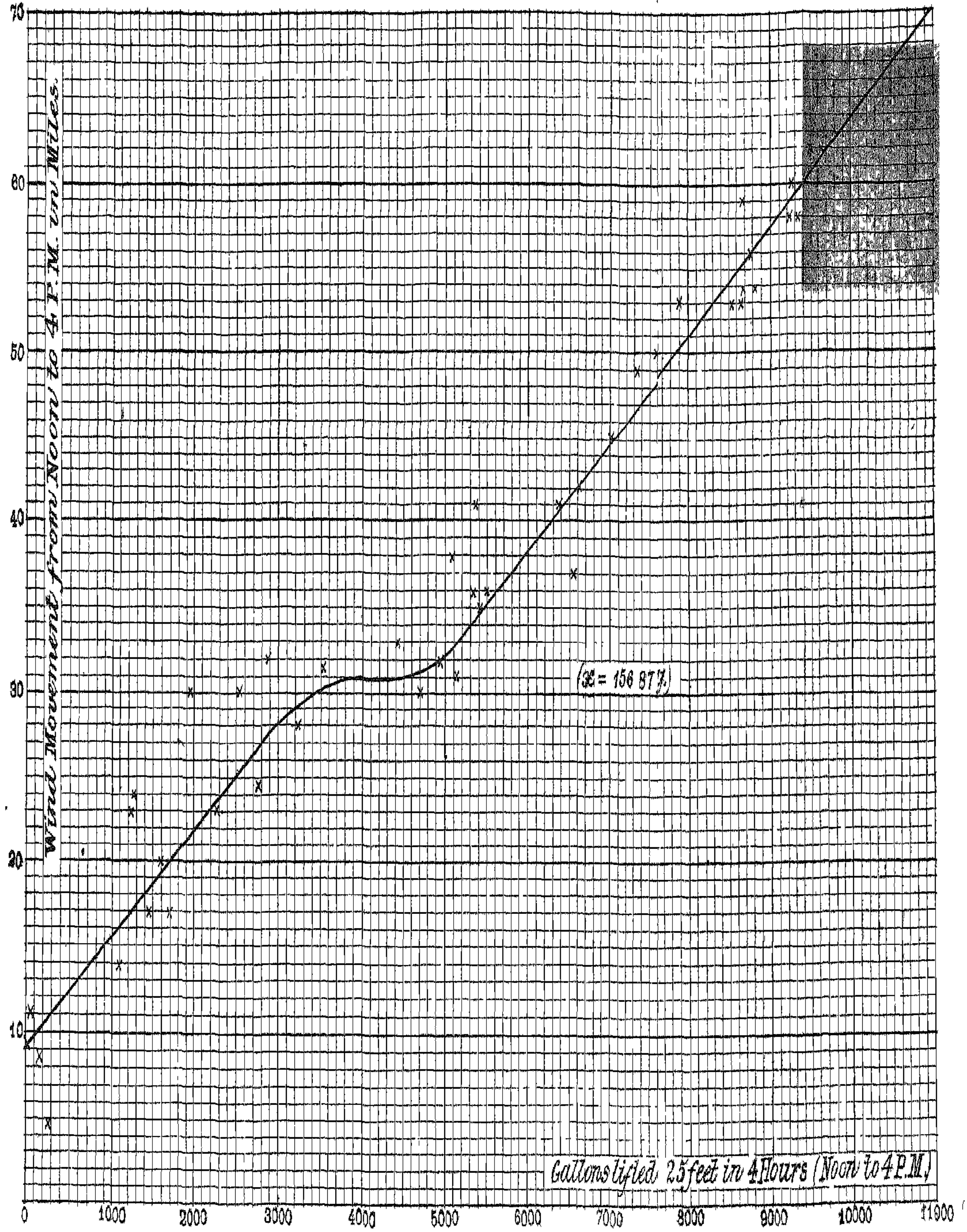

45000
4000
35000
30000
25000
20000
15000
10000
5000
Gallons lifted 25 feet per day
x - 175 (y - 53)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Wind Movement in miles per day

PLATE II.


Wind Movement from Noon to 4 P.M. in Miles.
70
60
50
40
30
20
10
(x = 156 87%)
Gallons lifted 25 feet in 4 Hours (Noon to 4 P.M.)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000